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SOIL STABILIZATION USING BITUMEN EMULSIONS (BODENSTABILISIERUNG--ETC(U)
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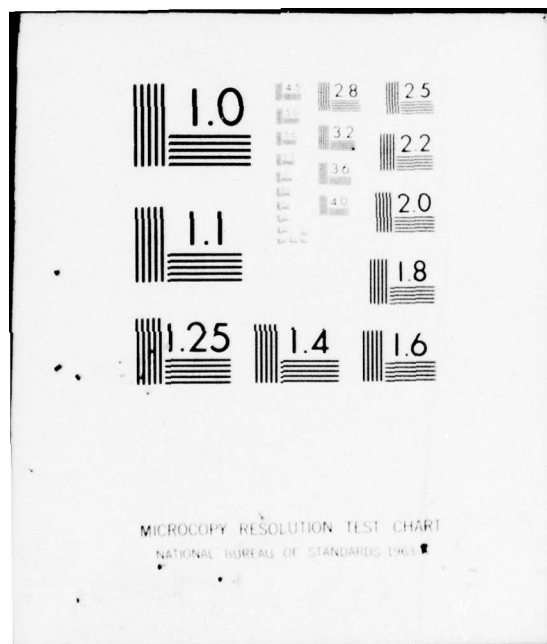
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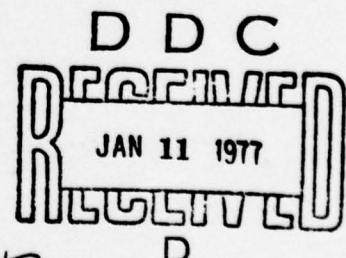


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SOIL STABILIZATION
USING BITUMEN EMULSIONS

M. Blumer



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SOIL STABILIZATION USING BITUMEN EMULSIONS

By Engineer E. Blumer, ETH [Confederation Technical College], Hünibach-Thun, Switzerland

Our activities in road construction in many instances must be governed by facts which we cannot influence. Such external prerequisites for example include the following:

The tremendous increase in the number of motor vehicles and the higher percentage of heavy vehicles and freight. The numerical and weight increase in the traffic volume leads to a noticeable increase in the stress on the road body. Many roadways no longer meet modern requirements and there is a real and urgent need for restoring existing roads and making them more efficient.

On the other hand, available public funds have become extremely scarce and moreover we do not have the manpower needed to meet the demand for construction work.

There is yet another factor which will increasingly influence our future endeavor. We must become aware of the increasing threat to the environment and we may now carry out only those construction projects which are "good for the environment." That means two things: first of all, we must keep harmful effects on the environment as small as possible, and, besides, we must not strip away our regenerative resources--and for us that means high-grade gravel sand.

There are three requirements which emerge from this situation as far as we road builders are concerned.

1. We must build cheaply and we must handle the rather scanty sums very economically. Available loans must be so used that the greatest possible useful effect will result as far as the road user is concerned.

2. We must achieve a high productivity level, that is to say, we must look for construction methods which require less in terms of working hours. In this way we will be reducing the construction time and we will need less manpower.

3. We must build in a manner that will be good for the environment by confining ourselves to the absolutely necessary minimum in using high-grade minerals and by trying to get along with the least possible transportation volume.

These three requirements are in keeping with the methods of using bitumen emulsions in road construction as described below.

1. Effect of Bitumen Emulsions

The following effect results from mixing bituminous bonding agents into a soil: "Lasting stabilization through production of a flexible, frost and water resistant layer with increased carrying capacity." Let us take a closer look at these effects of bituminous binders.

Frost and Water Resistance

It is known that natural soils become unstable under the action of water or frost when the share of the grain sizes ≤ 0.02 mm comes to more than 3% and when the material must be classified as being vulnerable to frost. Ground frost can then form ice lenses and, during the thaw, the carrying capacity is reduced.

These disadvantages can be eliminated when we mix a bituminous binder in; the road body remains frost and water resistant and this is true even when it is made up of material with larger silt and clay portions. If we stabilize the foundation layer, then we may also use frost-sensitive, second-grade gravel sand without any reason to fear damage.

Carrying Capacity and Stability

By mixing in bituminous binders and as a result of the subsequent compacting [consolidation], the grain structure is permanently sealed [cemented]. The load distribution of the stabilized layer is about 2-2.5 times greater than that of the unbound foundation layer. We can therefore achieve a definite saving in terms of gravel sand if we provide for stabilization. In addition we have the fact that the stabilized layer forms a permanently stable support for the bituminous carrying layers and covering layers. Unlike the gravel sand foundation layers, there is no danger that the covering layers might be excessively stressed because of loosening phenomena in the subjacent layers and that cracks might develop.

Flexibility

The fact that a bituminously stabilized layer retains a certain minimum flexibility is absolutely desirable. In highway construction--especially in building roads of secondary significance--we can hardly afford to spend so much that subsequent settling and frost swelling will be entirely impossible. This is why we must select supporting layers here which can adapt to the deformations of the foundation without cracks. In case of rigid supporting layers, the risks of crack formation are greater, unless we greatly increase the layer thicknesses.

The previously mentioned advantageous effects apply to all bituminous binders which are customary in soil stabilization (road tar, bitumen emulsions, cutbacks). The following facts apply specifically to bitumen emulsions.

The binder need not be heated; we get low vapors and odors which constitute an annoyance to the workers and the neighborhood. The emulsion is thin-flowing and can be easily mixed. Due to good mixability with moist material and the high wetting capability, the dosing may be somewhat less than that of other bituminous binders.

The time available for mixing and condensation is longer; it can moreover be correspondingly controlled by chemical additions in keeping with the particular situation.

Stability and bitumen content of the emulsion can be adjusted to the makeup and grain size graduation of the soil.

2. Areas of Application

The following areas of application are favorable from the technical and economic viewpoints for stabilization with bitumin emulsions:

Stabilization of topmost layer of gravel layer in construction of new roads;

Stabilization and dust removal on gravel roads and tracks;

Roadbed reinforcement on existing roads;

2.1. Construction of New Roads

We have become accustomed to building roads with frost-proof gravel sand and reinforcing them with bituminous hot-mix supporting layers and coatings. This "conventional" road superstructure undoubtedly has proved itself but it by no means constitutes the optimum solution in every case.

1 Boden	2 Verkehr	3 Senkrecht ≤ 30 Lkw/Tag	4 Leicht 31-100 Lkw/Tag	5 Mittel 101-300 Lkw/Tag
7 CBR min. 20% Kiese und sandige Böden (auch silty und tonige Kiese, z.B. Schotter und Bachschnitt)		10 cm 20 cm ca. 30 cm 13	8 Oberflächener- haltung 15 cm 25 cm ca. 40 cm 13	5 cm Belag 9 12 cm Stabilisierung 10 ca. 30 cm Kies sand 11 ca. 45 cm
12 CBR min. 5% Silt und tonige Silt (z.B. in Moränen, Lehne, Geränge- schnitt)		10 cm 40 cm ca. 50 cm 13	8 Oberflächener- haltung 15 cm 50 cm ca. 65 cm 13	5 cm Belag 9 12 cm Stabilisierung 10 ca. 80 cm Kies sand 11 ca. 75 cm

Figure 1. Examples of Stabilized Roadbed Structures. Dimensioning as Function of Soil-Carrying Capacity and Anticipated Traffic Volume.

Legend: 1--Soil; 2--Traffic; 3--Very Light; 4--Light; 5--Medium; 6--Truck per Day; 7--CBR Minimum 20%, Gravelly and Sandy Soils (also silty and clayey gravel, for example, crushed rock and creek rubble); 8--Surface Treatment; 9--Covering Layer; 10--Stabilization; 11--Gravel Sand; 12--CBR Minimum 5%, Silts and Clayey Silts (for example, in moraines, loam, slope rubble); 13--Approximately.

An alternative to this is the road superstructure where the uppermost layer of the gravel layer is stabilized bituminously and which--depending upon the anticipated traffic volume--gets no or gets only a relatively thin wear-and-tear layer made of bituminous hot-mixed material (Figure 1).

This kind of roadbed superstructure will be advisable under the following conditions:

1. No suitable, frost-proof, gravel sand is available at reasonable prices. Because we reduce the effect of frost and water through stabilizing, we can also use second-class materials which would not be permissible in the natural state. We can find such materials perhaps in the immediate vicinity of the construction site or, if the situation is particularly favorable, perhaps even in the trace itself.

2. The available gravel sand is not well graduated and is only very difficult to compact. That happens, for example, when we get material from water bodies. The strength increase connected with stabilization permits the use of this material likewise.

3. The construction site is remote or difficult to reach so that we encounter heavy transportation costs. By stabilizing materials available on

the spot, we can cut down the required transportation volume and its undesirable side effects to the absolutely necessary minimum.

4. The foundation layer is to serve as a transport track or--in case of highway straightening projects--as a provisional roadbed. This function can readily be performed by the bituminously stabilized layer; it has sufficient supporting strength and protects the subgrade and the subjacent foundation layer against damage by traffic and water.

5. The highway must be completed for traffic phase by phase (for example, road repair or straightening while maintaining flow of traffic). This can be accomplished comparatively simply in connection with the method of superstructure stabilization using bitumen emulsion "mixed in place" and without impermissively severe interference with moving vehicles.

2.2. Stabilization of Gravel Roads

Macademized, unpaved roadways require comprehensive and correspondingly expensive maintenance considering today's high wages. They are eroded by surface water--natural roads on upgrades frequently resemble a creek bed more than a road--and they are worn down by vehicles with tires. In every natural road there comes a moment when we will have to ask the question as to whether continuing maintenance is worth the trouble. In many instances the amount to be spent annually is so great that a simple paving of the road could pay for itself in a few years. If loans are not sufficient for a complete improvement, one should try to achieve at least a partial restoration by improving the worst places, such as curves, steep upgrades, etc.

The superstructure of gravel-covered side roads as a rule does not have a very high carrying capacity. Surface reinforcement must therefore be in a position to adjust to settlement without the development of cracks because, for economic reasons, it could hardly be made so thick that the existing carrying capacity would be considerably improved. This requirement is met by stabilization using bitumen emulsions. It represents a suitable means for dust removal and reinforcement of an existing natural road because the existing--as a rule hardly frost-proof--layer need not be taken off because stabilization reduces the risk of frost and thaw damage and at the same time increases the carrying capacity at least on a ratio of 1:2. The load distribution of a 10 cm thick stabilized layer roughly corresponds to a 20-25 cm thick layer of unbound materials.

Emulsions must as a rule be mixed in to a depth of about 10-20 cm. It is recommended that we determine, by means of probes, how thick the existing crushed rock layer is and that we make a determination of the subjacent underground or foundation. On the basis of these prerequisites we can then dimension the superstructure (see also Figure 1).

If the carrying capacity improvement through stabilization of the existing crushed rock layer is not enough--and that can happen when the anticipated

traffic volume is relatively heavy and when the existing foundation layer is very weak--then we can achieve an increased load-distributing effect

By applying additional gravel sand material prior to stabilization or

By building in an asphalt-carrying layer or a hot-mix coating on top of the stabilization.

Like existing natural roads, we can stabilize and render dust free simple transport tracks and factory or farm roads by means of a 10-20 cm fixed stabilization using bitumin emulsion. Here again we can under certain circumstances achieve considerable savings by eliminating the continuing maintenance work and by reducing the transportation cost (possibility of faster speeds).

2.3. Superstructure Reinforcement

The adaptation of inadequately load-bearing roadways to present-day and future traffic conditions has become an important and urgent task of road builders. Major road damage, especially grid-shaped cracks, as a rule are due to the road's insufficient carrying capacity during the thaw. This conclusion is particularly obvious when, in the torn areas, we can see crushing in the area around wheel tracks. To restore such a road, the superstructure has to be reinforced. Superstructure reinforcement is required also when a comparatively weak road in the future will have to handle increased and heavier traffic volume. There a

There are various methods to reinforce the superstructure of an existing road; three methods are illustrated in Figure 2.

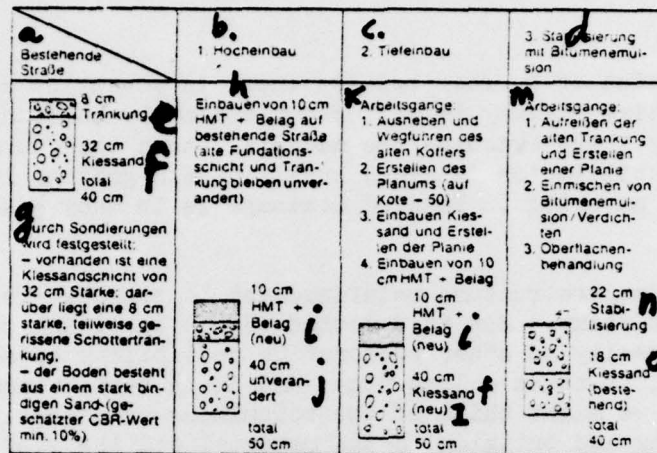


Figure 2. Method for Reinforcing Existing Roads

Legend: a--Existing Road; b--1. Top Insertion; c--2. Deep Insertion; d--3. Stabilization With Bitumen Emulsion; e--Impregnation; f--Gravel Sand; g--Probes Determine the Following: 32 cm thick gravel sand layer present, on top of it, and 8 cm thick, partly cracked crushed rock impregnation, soil consists of strongly cohesive sand (estimated CBR value at least 10%); h--Built in 10 cm HMT [abbreviation unknown] + Coating on Existing Road (old foundation layer and impregnation remain unchanged); i--Coating (new); j--Unchanged; k--Work Operation: 1. Take out and remove old crushed-rock layer; 2. Make subgrade (at elevation-50); 3. Built in gravel sand and make level plane; 4. Built in 10 cm HMT + Coating; l--New; m--Work Operations: 1. Tear up the old impregnation and make a level plane; 2. Mix in Bitumen Emulsion, consolidate; 3. Surface Treatment; n--Stabilization; o--Gravel Sand (existing).

Top Insertions

In the so-called top insertion [high insertion], bituminous mixing material is directly built into the existing cover [surface] without any change in the existing road body. This method is economical because it does not involve a fundamentally new construction but rather nearly a buildup in which the available carrying capacity of the existing road body is also used. The method moreover is not harmful to the environment and only takes a short time to carry out; it is therefore used wherever local conditions permit. Reinforcement using top insertion is not feasible

When this is connected with extensive adaptations to secondary roads, walkways [sidewalks], curbstones, shafts, etc. (especially in towns) or

When the existing road reveals such heavy damage that the bituminous layer required for reinforcement would have uneconomically great thicknesses.

Deep Insertion

The extreme solution of surface reinforcement is so-called deep insertion, in which the entire roadway is lifted out and newly built up. We lift the entire road body out and evacuate the material; then the foundation layer and the bituminous stabilization is again built in with greater layer thicknesses using suitable materials. Renewed drainage is in many cases connected with deep insertion.

This solution of superstructure reinforcement is probably the most reliable and the least risky. But this method should be picked only in those cases where there is really no other restoration possibility because it is mostly very expensive, it takes a long time, and it is rather harmful to the environment; here we might think of the voluminous transportation work required for evacuating and bringing in the material and the need for using high-grade gravel sand deposits.

Stabilization

Where top insertion cannot be considered for technical or economic considerations, the following solution might under certain circumstances be implemented as a compromise between top and deep insertion:

Remove the old roadway stabilization; make a new subgrade; where necessary, supplement with outside material brought in;

Mix in bitumin emulsion to a certain depth (which results from the dimensioning); consolidate and restore subgrade;

Apply a wear-and-tear layer (OB [abbreviation unknown] or surface coating) or, possibly, insertion of bituminous stabilization.

This method of superstructure reinforcement as a rule is more economical than complete crushed-rock layer removal. The construction time is shorter, we need not tap the deposits of high-grade gravel sand, and the transportation volume is at a minimum. The method is practical especially when the foundation layer of the existing road is not strong enough or not sufficiently frost proof.

By stabilizing the existing material with the bituminous binder, we can improve the carrying capacity and we can reduce the frost damage risk.

The retread method represents a special case of such stabilization. It can be used when the existing road is only slightly stabilized (for example, surface treatment or crushed rock impregnation). In these cases, the layers, which are bound together by the bonding agent, are not taken off and removed but are rather used along with the rest by tearing them up and mixing them with the bitumen emulsion.

The dimensioning of such superstructure reinforcement can be accomplished according to the customary method. Using probing slits, which are to be made in representative places, we measure the existing layer thicknesses and we determine the soil category.

The required thickness of the foundation layer emerges as a function of the soil-carrying capacity and the anticipated traffic volume. By comparing the actually existing thickness of the foundation layer with the required thickness, we can then figure out the depth at which we must stabilize in order to achieve the required carrying capacity in the superstructure. Here we may assume that the effect of stabilized layers will be 2-2.5 times greater than that of unbound layers (Figure 3).

3. Preliminary Investigations

Bitumin emulsions can be used not only for stabilization of noncohesive but also of cohesive soils; the permissible grain size distribution range extends from unfixed gravel and sand all the way to silty and slightly clayey materials (Figure 4). In soils with a very large percentage of very fine grain sizes, the method of course no longer becomes worthwhile, in economic terms, because these soils require a high bonding agent dosage.

The dosage must be coordinated with the existing soil material so that we will get sufficiently high strength and water resistance of the mixture. For bitumin emulsions we do not have any standardized guidance at this time when it comes to conducting dosage experiments. In the United States--where stabilizations using bitumen emulsions for silty soils, sand, and gravel sand are customary--various methods are used for examining the strength and investigations are also conducted to determine the optimum binder content according to various methods (1).

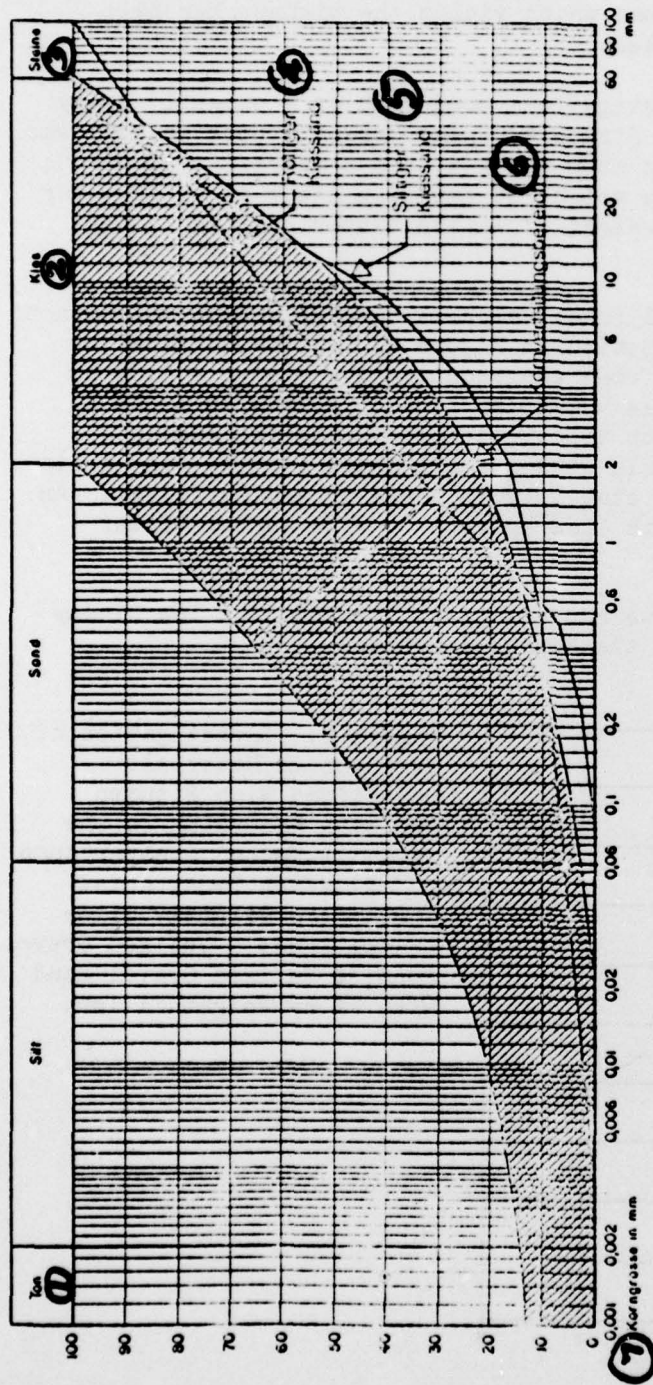


Figure 4. Grain Size Distribution Spread for Stabilization Using Bituminous Binders According to Swiss Regulations (2).

Legend: 1--Clay; 2--Gravel; 3--Stones; 4--Unfixed Gravel Sand; 5--Silty Gravel Sand; 6--Grain Size Distribution Range; 7--Grain Size in mm.

A modified Marshall method is frequently used; here the testing bodies are pressed at 25° C (177° F). Here we seek to attain a stability of at least 340 kp (750 lbs.); the binder content which yields the highest Marshall stability is considered to be the best.

Figure 5 illustrates the investigations conducted on a slightly silty gravel sand (grain distribution in Figure 4). The Marshall testing body was stored moist for three days and was then pressed at a temperature of 20° C; the optimum binder content is 5% by weight of emulsion (that is to say, for the 60% emulsion used it is 3% by weight of active binder related to the soil's dry weight).

The very clean, unfixed gravel sand, which is very difficult to compact in the natural state (grain distribution in Figure 4) was investigated at a binder content of 5% by weight of 60% emulsion (active binder = 3.0% by weight). The Marshall stability was 400 kp at 20° C. By mixing in 4% by weight of filler, it was possible to improve it to 590 kp (see Figure 5). This means that--in case of materials with a small share of very fine grain sizes--we can achieve a noticeable stability increase by adding filler. An even greater effect is achieved with lime hydrate or with mortar binder [cement].

From the diagram (Figure 5), we can see that, in case of a low binder content, the strength increases as the dosage increases.

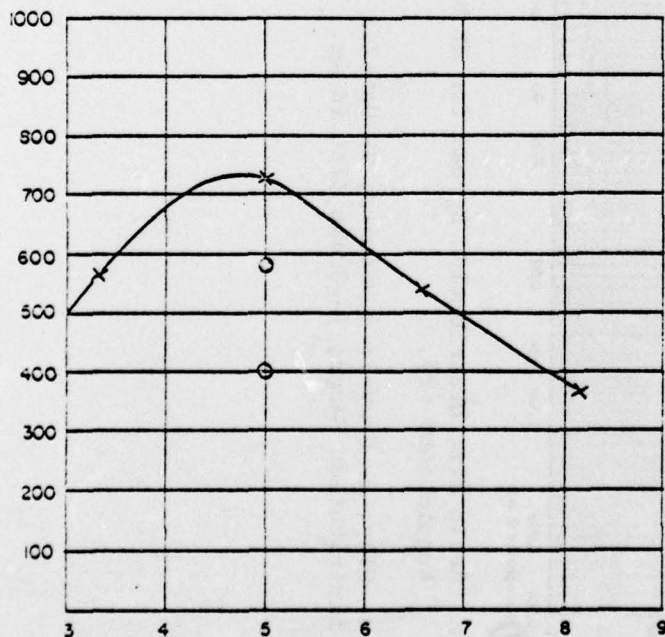


Figure 5. Investigation of Strength in Materials Stabilized With Bitumen Emulsion According to the Marshall Method (temperature 20° C) after 3-day Moist Storage; x Slightly Silty Gravel Sand; o Unfixed Gravel Sand; ● Unfixed Gravel Sand With 4% by Weight Filler.

This is connected with the fact that a better groove effect is connected with the increase in the binder content. From a certain binder content onward, on the other hand--that is to say, when all mineral grains are completely enveloped--the strength increases with increasing dosage because the binder film becomes thicker and because the "lubricating effect" reduces the friction between grains. On the other hand, as the binder dosage increases, we get mixtures with greater resistance to the action of water and with greater durability. This is why the strength in many places is not considered the only criteria in determining the optimum binder content.

A method, which includes additional viewpoints, has been proposed by Winterkorn (3). Accordingly, sample bodies are stored dry and in water and that binder share, at which the ratio between the strength after dry storage and strength after water storage is greatest, is considered to be the best--whereby the strength after water storage is supposed to be at least 5.27 kp cm².

An approximation solution for the determination of the optimum binder content is being used in Oklahoma (1). It is based on the fact that one estimates, on the basis of the grain distribution curve, which mineral surface will have to be enveloped. Here is the formula for the bitumin emulsion:

$$p = 0.05 \cdot a + 0.1 \cdot b + 0.5 \cdot c$$

whereby p = binder content (50% emulsion) in percent by weight related to the dry weight of the material.

a = % by Weight of Mineral 2mm

b = % by Weight Mineral 2mm but 0.074 mm

c = % by Weight Mineral 0.074 mm

According to this formula, we would get the following binder contents for both materials whose grain size distribution curves are given in Figure 4:

Unfixed gravel sand p = 6.8% by weight, 50% emulsion,

Silty gravel sand p = 8.2% by weight, 50% emulsion.

As standard value we can assume that, for a gravel sand, we need roughly 3.0% by weight of active binder and that we need about 3.5-4.0% for some of the more fine-grain soils. When we use a 60% emulsion, that would come to between 1.0 kg and 1.3 kg emulsion per m² of surface area and per cm of mixing depth--assuming a drying space weight of 2.0.

4. Operational Phase

The stabilization using bitumen emulsion mentioned here are performed according to the so-called local mixing methods (mixed in place), that is to say, the locally available or the brought-in material and the binder are mixed with a mobile mixer. The binder is added during the actual stabilization method simultaneously with the mixing phase whereas in the retread method the emulsion is put in first.

4.1. Stabilization Method As Such

Loosening

If we want to stabilize heavily precompacted foundation layers--which will apply in the case of natural roads and lightly paved roads (for example, crushed rock impregnation)--then the material must first of all be loosened up down to mixing depth (ripping unit attached to grader, tractor, roller, or bulldozer). Hot-mix supporting layers and coatings are loaded up and carried away. Likewise, rocks larger than 100 mm must be screened out (by hand or with the stone rake) and must be removed.

Grading

Because mixing equipment as a rule cannot do any grading or can do so only inadequately, it is necessary to prepare a subgrade in keeping with the profile and to roll it. Where necessary, the subgrade is supplemented with outside material brought in by way of addition (0-60 mm, possibly 0-30 mm).

Mixing

Bitumin emulsions are mixed with special stabilization equipment which is self propelled or which can be hitched to a tractor or prime mover and which are then equipped with one or two mixing rollers. Because the emulsion is sprayed directly into the mixing chamber from a spray bar and because this is done at the moment when the material is being whirled up by the grinding roller [shaft], we get uniform mixing. In many instances a single mixing operation is enough (especially if the equipment is provided with two rollers); otherwise, a second passage is needed without binder addition.

The emulsion is supplied in a tank car. The latter drives ahead on the subgrade and is connected with the dosing device of the stabilization unit by means of a hose. The required dosage can be maintained with sufficient accuracy in modern equipment. The injected binder quantity is a function of the forward speed and the pressure; the through flow quantity can be read off on measurement instruments.

Compacting

The [steam] rollers customary in road construction are used for compacting (smooth-casing, vibration, or pneumatic rollers). Light preliminary rolling

is recommended directly behind the stabilization unit and followup rolling should be done with heavy equipment if the emulsion is broken. It is also a good idea to use a pneumatic roller because the latter has a kneading action. If necessary, stabilized material must be graded once again.

4.2. Retread Method

The retread method developed by Retread (Roads) Ltd., Herford, Great Britain, is suitable for stabilizing the foundation layer to a depth of 8-10 cm. The work phases are as follows: loosening, grading, and compacting remain the same as in the actual stabilization method but the mixing of the emulsion is different.

The graded material is first soaked with a bitumen emulsion. In this operation we have advantageously used a tank car which is equipped with a telescope-like adjustable sprinkling bar. For mixing we use a special mixing unit designed for this method; it can be mounted on a tractor. To insure perfect envelopment of mineral materials with the bitumen emulsion, we spray and mix in half of the desired binder quantity in the first step and we then repeat the process in a second step.

4.3. Wear Layer

Bituminously stabilized layers can be directly driven on after compacting. If no additional buildup is provided with an asphalt supporting layer and/or bituminous coatings (roadbed structures for medium traffic volume in Figures 1 and 3), then it is recommended, after some time, that we apply a wear layer. In simple cases, that will be surface treatment; in other cases we will provide sand asphalt or a 2-3-cm thick covering layer.

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